Need For a 21st Century Engineering Curriculum

CIMdata Commentary

Key takeaways:

- *The rapid pace of technology change associated with scientific computing and digital engineering has led to a profound change in the skills that engineers need to effectively perform their roles.*
- *CIMdata believes that U.S. universities are not adapting engineering curricula quickly enough to meet the needs of industry, particularly for mechanical engineering.*
- *Today's engineers need to learn how to effectively apply digital (virtual) modeling and simulation technologies within the context of their core engineering courses, in hands-on applied research projects and co-operative education programs.*
- *The reward and recognition system for faculty at many universities is not in synch with producing engineers who are "job ready" to apply today's cutting-edge engineering technologies.*
- *While there are several university success stories, academic leadership must work more proactively and closely with industry to define and implement a next-generation 21st Century engineering curriculum.*

CIMdata consultants, as well as representatives of the product lifecycle management (PLM) software industry, have been involved with STEAM[1] higher education for decades. Often, this is in the form of participation on advisory boards for university programs and initiatives, as well as providing grants of free commercial software and training in the use of state-of-the-art modeling and simulation software tools.

Dr. Keith Meintjes, CIMdata Fellow, has been involved with the Swanson Program at Cornell University for nearly 20 years. The program was personally endowed by Dr. John Swanson, the founder of ANSYS Inc., with the specific goal of integrating the use of simulation (i.e., physics-based CAE) tools into the undergraduate mechanical engineering curriculum. ANSYS Inc. has also provided grants of ANSYS CAE commercial software and student training for this program.[2] This groundbreaking Cornell program is a very successful model that has led to similar initiatives at several other leading U.S. universities.[3]

Since 2008, Mr. Don Tolle of CIMdata has been actively involved with the University of Cincinnati (UC) College of Engineering and Applied Science, and currently serves as Vice Chairman of the External Advisory Board for the Department of Mechanical & Materials Engineering (MME). Motivated by Cornell university's simulation education efforts cultivated over the past decade, the UC MME Department has formed partnerships with industry (Procter & Gamble, and GE-Aviation), as well as Siemens PLM Software, which has led to education and research training centers where engineering students get hands-on exposure to the application of PLM, CAD, and CAE technologies in the classroom, as well as in real world research projects.[4]

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[1] Commonly known as "Science, Technology, Engineering, Art, and Manufacturing"

[2] See https://www.mae.cornell.edu/mae/facilities/swanson-laboratory-advanced-simulation

[3] See https://www.cimdata.com/en/download-the-swanson-program-at-cornell-university

[4] See https://ceas.uc.edu/research/centers-labs/siemens-simulation-technology-center.html and https://ceas.uc.edu/research/centers-labs/uc-simulation-center.html

In spite of the success of these and a few other programs at selected U.S. universities, the Swanson Advisory Board (SAB) at Cornell is concerned that we are not progressing nearly fast enough to support the needs of industry in the 21st century. The SAB has a concern that perhaps a plateau has been reached within the constraints of the current engineering curricula that are very segmented within their traditional disciplinary silos. Currently, the typical engineering curriculum is not being updated quickly enough, and, in many cases, the “systems thinking” and digital engineering skills that prospective employers in industry and government are looking for are not taught properly or sufficiently.

To understand the significant business impact of digitalization: Moore’s Law says that technical computing capability doubles every 18 months; that is, ten times in five years, a hundred times in ten years. The computing capability to model and simulate product performance with ever-increasing scale and accuracy will continue unabated. Further, it is reasonable to expect the people, equipment, and facilities costs required for physical testing to support product validation will increase by approximately 7% per year, which is a doubling in ten years. Putting this together, the leverage of digital simulation and validation vs. physical testing will change by a factor of about 200 in just ten years. What are universities doing to react to that reality?

In the context of global industry trends such as the Internet of Things (IoT) and Industry 4.0, companies are now faced with applying an ever growing array of new digital modeling and simulation technologies for product design, development, production, and sustainment, including artificial intelligence and machine learning, multidiscipline integration and optimization of complex cyber-physical systems, physics-based digital twins, new advanced hybrid materials, generative design, and additive manufacturing (3D printing), to name a few. Major companies may have intern programs lasting up to five years to teach key skills to newly hired, freshly minted engineers, but they still want and need new engineers to be productive much sooner. It is one thing to have an engineer go through an intern program to gain experience, and product and process knowledge specific to their industry and company, but it is a very different matter to have to teach them fundamental engineering knowledge and skills they could have (or should have) been taught as undergraduate students.

As an example, Dr. Meintjes has often complained of the untold hours he spent learning to use perturbation methods to solve nonlinear differential equations. Today, one would simply use a commercial tool such as Matlab or Maple. One of the faculty at a leading engineering school said, “Oh yes, we still teach that manual process.” So then, how do we balance the needs to teach an application tool, as well as the fundamental engineering understanding needed to ensure correct and proper use of current tools? And in updating the current engineering curriculums, there is always the burning question: If you’re going to add something new, what course content are you going to take out? One engineering dean sadly quipped: “The curriculum is changing slowly, one faculty retirement at a time.”

Other observations of the current situation:

- The specific software tools used when training students are not the critical issue. The vast majority of today’s commercial software tools are highly capable in multiple physics disciplines. Students should be taught the “Process of Modeling and Simulation” that we see as a layer added on to the Scientific Method (which many schools also don't teach).[5]
- The reward system for academics, particularly at research oriented-universities, is at odds with the end customers of the universities: the engineering and

[5] See https://en.wikipedia.org/wiki/Scientific_method

manufacturing companies who will hire these students. Academics are often rewarded as individuals based on the recognition of their colleagues via publications and the research funds they can generate. These are also key success metrics for obtaining a tenured position—perhaps the most important personal objective for most engineering faculty members. Many of the faculty are also often not adequately recognized for the quality of their primary product: namely graduating “job ready” engineering students.

- Many students absolutely love competitive team activities such as senior research projects, Formula SAE or STEAM robotics challenge teams. Again, the reward and recognition that faculty get for supporting these types of efforts is comparatively low. But, for hiring companies, success in such projects that involve collaboration, teamwork, and multidiscipline integration, is very influential in their hiring decisions.
- A number of engineering schools now provide co-operative education programs that provide one or more semesters where undergraduate students work for industrial companies on real world engineering projects with experienced engineers. This hands-on experience is an invaluable complement to formal classroom training and better prepares students to enter the work force. At some schools such as Drexel University and the University of Cincinnati (the birthplace of co-operative education) participation in the co-op program is mandatory for all undergraduate engineering students. But co-op participation is still not mandatory at the vast majority of engineering schools.
- Software licenses and accessibility are typically not the limiting factors. Most leading CAE software companies such as ANSYS, Altair, Dassault Systèmes, MSC Software, and Siemens PLM Software have “free” student versions with extensive modeling capabilities and generous problem size limits that are adequate for teaching. But there are also many instances where universities have received large software donations from these companies and the software has sat unused since the students have not been adequately trained to use and apply simulation tools to real world problems.
- Just like any enterprise, universities have to set up the infrastructure to license software and deploy software to students. Therefore, it is entirely rational for universities to standardize on particular software choices to minimize support costs. Experience shows that while students become native users of the chosen software, they are also adept at switching between applications. What is important is that the applications become “sticky” as real-world experience is accumulated through use in formal co-op programs and/or collaborative project team activities such as Formula SAE. The PLM solutions, including simulation software, can also serve as a technical memory to pass on knowledge to other team members and future students via use of simulation process automation applications and data management tools.
- A major limiting factor, apart from the reward structure, is that most faculty are not adept at understanding real world industry-standard applications unless the tools have been utilized as part of applied research programs. Even when they are familiar, there is a lack of high-quality course content that can be used to bring the use of simulation tools into the curriculum in a way that connects to the fundamentals being taught. Cornell has been addressing this by developing free online content including a massive open online course (MOOC) and

SimCafe.org. The MOOC has over 100,000 people enrolled from 176 countries while also being used in multiple Cornell undergraduate engineering courses.[6]

- Scaling up such efforts can be achieved if both industry and technology providers donate cash grants to faculty to develop, share, and deploy curriculum materials that embed the use of commercial software simulation tools. One such program was initiated at the University of Cincinnati during 2017 with Siemens PLM Software. The school continues to expand the scope of courses offered with the embedded use of Siemens simulation technologies.[7]

Concluding Remarks

Ultimately, students are not being provided with an understanding of the key role that modeling and simulation provide in the context of current and future digital engineering processes that rely on the use of sophisticated models throughout the entire product lifecycle—starting from requirements and concept ideation through systems design, product manufacturing, and in-service utilization. All engineers should be taught this as part of their courses and/or hands on projects. Even if engineers do not end up doing digital modeling and simulation in a future job, they surely will be consumers of the models, data, and simulation results that have been created by other engineers within their organization, as well as by their design partners and global supply chain.

Students, like their faculty, predominantly receive academic recognition for individual course achievement. Faculty are often judged and compensated based on the volume of scholarly publications and research grants obtained. This is counter to what companies need, which is a focus on applied learning and an open environment of teamwork and collaboration. Recognition and rewards systems need to be modified for both faculty and students to encourage the desired outcomes.

Most engineering schools are organized around deep technical silos based on the engineering academic sub-disciplines. The reality now in industry is that product engineering of complex cyber-physical systems is a multi-disciplinary and collaborative endeavor that spans many physics-based mechanical disciplines (i.e., structures, fluids, thermal, materials, etc.), as well as cuts across the functional domains of electrical, software, controls, chemical, biological, etc. Engineering college deans must get creative and figure out ways to foster cross-discipline collaboration and hands-on learning within and across their various departmental silos and, indeed to other faculties like Business. This is no small task given the relatively rigid structure of the engineering curriculum required by college accreditation bodies today such as ABET (Accreditation Board for Engineering and Technology), but it must be addressed from the top down. Some universities have addressed these issues by creating programs whereby students can get cross-domain degrees in Computational Engineering, Biomedical Engineering, and Systems Engineering that span multiple academic disciplines. Academia should evaluate and encourage the growth of those types of engineering programs and curricula as potential templates for sharing of educational best practices across universities.

Industry also has a very key role to play in effecting this evolution towards a next generation engineering curriculum. As the ultimate employers of tomorrow's students, industry must demand more accountability of academia in producing "job ready" engineers. This can be accomplished by engaging proactively with leading engineering schools to better communicate industry's business and engineering challenges and to help define specific curriculum initiatives

[6] See https://goo.gl/Ce2zKz

[7] See https://ceas.uc.edu/research/centers-labs/siemens-simulation-technology-center/courses---projects.html

that academia can pursue to better prepare tomorrow's engineering students. While our focus here is on simulation and mechanical engineering, other curricula are feeling the stress of rapidly changing technology and work processes.[8]

The product engineering and manufacturing communities stand to benefit by helping create a next generation curriculum that better prepares students to be highly productive engineers in the 21st Century and beyond.

About CIMdata

CIMdata, an independent worldwide firm, provides strategic management consulting to maximize an enterprise's ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM). CIMdata provides world-class knowledge, expertise, and best-practice methods on PLM. CIMdata also offers research, subscription services, publications, and education through international conferences. To learn more about CIMdata's services, visit our website at http://www.CIMdata.com or contact CIMdata at: 3909 Research Park Drive, Ann Arbor, MI 48108, USA. Tel: +1 734.668.9922. Fax: +1 734.668.1957; or at Oogststraat 20, 6004 CV Weert, The Netherlands. Tel: +31 (0) 495.533.666.

[8] Are Students "Real-World" Ready? CIMdata White Paper, May 2017, https://www.cimdata.com/images/Downloads/CIMdata_Siemens_Whitepaper_Education_8May2017.pdf